EOLOGICAL SURVEY AND MUSEUM.

GUIDE

TO THE

GEOLOGICAL MODEL

OF THE

ASSYNT MOUNTAINS

BY

B. N. PEACH, LL.D., F.R.S.,

AND

J. HORNE, LL.D., F.R.S.

Examples of this model are exhibited in :—

The Museum of Practical Geology, Jermyn Street, London ;
The Royal Scottish Museum, Edinburgh ;
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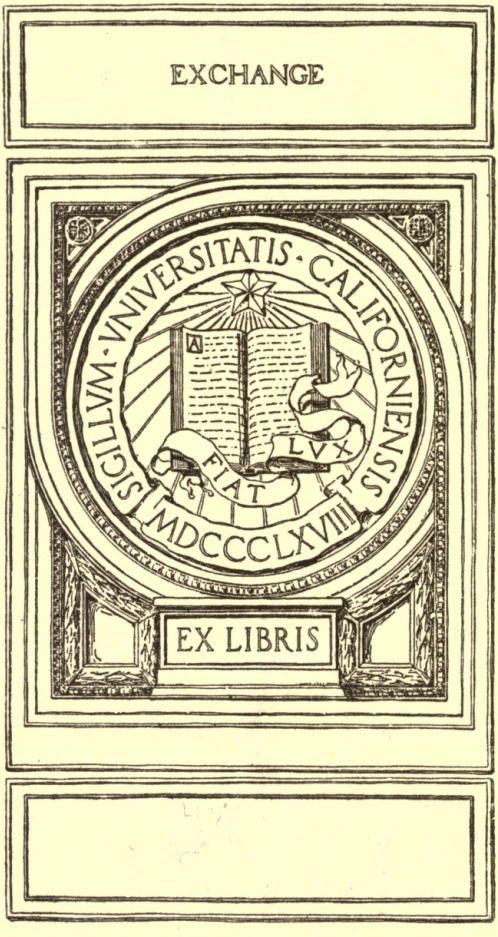

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PREFACE.

THE region illustrated by this Model can scarcely be rivalled for the variety and interest of its tectonics, or for the clearness with which they are displayed. The history of the prolonged investigations by which the true sequence of geological formations and the effects of the tectonic movements were determined has been told in the Memoir on "The Geological Structure of the North-West Highlands." From that volume we learn of the first advances in establishing the stratigraphy made by Macculloch in the early part of the last century, and of the efforts made by Murchison and other observers to explain what appeared to be a sequence upwards from Lewisian Gneiss through fossiliferous deposits into the Eastern Schists. That such a sequence existed seemed indubitable on the evidence presented by one mountain-side after another, but that it represented a true succession of geological formations, superimposed in order of age, was keenly opposed by Nicol, and at a later date by Lapworth, Callaway, Bonney, and others. It was not, however, till the ground had been mapped in detail on the six-inch scale by the Geological Survey that it could be demonstrated that the supposed succession was everywhere deceptive, and due to the piling-up of the rocks by over-thrusting on a stupendous scale, an explanation which has since been found applicable in mountainous regions all the world over. In this survey Drs. Peach and Horne, the authors of this Guide, took a foremost part.

The North-West Highlands serve as a type-area for the study of earth-movements and mountain-building, and as such have attracted much attention from British and Foreign geologists. They are, however, difficult of access. The Model and this descriptive Guide have been designed to help those who cannot visit the ground itself, to form a conception of the physical features and of the grand tectonic structures with which they are related.

A. STRAHAN,
Director.

Geological Survey Office,
28 Jermyn Street, London,
26*th May*, 1914.

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GUIDE TO THE GEOLOGICAL MODEL OF THE ASSYNT MOUNTAINS.

I. INTRODUCTION.

THE geological model of the mountainous region of Assynt was prepared by the late Mr. Bowie from the Ordnance Survey maps on the scale of six inches to one mile ($\frac{1}{10560}$); the vertical and horizontal scales being the same. It represents an area of about 168 square miles, stretching from Loch Glencoul and the head waters of the River Cassley on the north to Loch Skinaskink and the northern flank of the Cromalt Hills on the south. Its orientation is not due north and south; its longer axis trends N. 33° E. and S. 33° W. This plan was adopted in order to include almost the whole of the tract affected by the post-Cambrian movements in Assynt, together with a considerable area of the undisturbed region to the west. The belt of complication is here from six to eight miles broad, and the phenomena connected with each successive overthrust are admirably displayed in many natural sections. It may further be remarked that the feature which distinguishes the terrestrial displacements in Assynt from those in other areas in the north-west Highlands is the conspicuous overlap of the Eastern Schists along the northern flank of the Cromalt Hills south from Loch Urigill. For these reasons the area represented by the model has been selected as illustrating with remarkable clearness the great post-Cambrian movements in the North-west Highlands.

II. PHYSICAL FEATURES.

In this region there is an intimate relation between the topography and the geological structure. In the tract lying to the west of the post-Cambrian displacements, each of the rock groups, viz.—the Lewisian Gneiss, the Torridon Sandstone, and the Cambrian Quartzite, gives rise to distinct physical features. Thus the Lewisian Gneiss forms an undulating rocky plateau, varying in height, on an average, from 500 to 1000 feet. It is comparatively bare of drift and dotted over with lochs. It stretches from Loch Skinaskink in the south-west corner, northwards by the upper reaches of Loch Veyatie and the head of Càm Loch to the southern flank of Suilven. Beyond that prominent ridge it sweeps round the western slopes of Canisp and Beinn Gharbh northwards to the shores of Loch Assynt.

It reappears on the north side of Quinag, and is well displayed on both shores of Loch Glencoul at Unapool and Aird da Loch.

The Torridon Sandstone forms detached mountains upon this rocky plateau, which are represented by Quinag (Spidean Còinich, 2508 ft.), Beinn Gharbh (1769 ft.), Canisp (2779 ft.), Suilven (2399 ft.), and Cùl Mòr (2786 ft.). One of their characteristic features is their terraced outlines, due to the outcrops of beds of grit and sandstone, either horizontal or dipping at gentle angles. Near the crests of two of these mountains (Quinag and Cùl Mòr) huge corries occur with prominent dividing ridges, which are traversed by numerous joints along which the denuding agents work more rapidly.

The next topographical type in the undisturbed area is produced by the Cambrian quartzites which give rise to snow-white escarpments and long bare dip slopes as in Quinag and Canisp.

The greatest mass of high ground occurs within the belt of complication. From Glas Bheinn (2541 ft.) a mountain range extends continuously in a south-easterly direction for nine miles by Beinn Uidhe and Mullach an Leathaid Rhiabhaich to Coinne-mheall (3234 ft.), and Ben More (3273 ft.). From that peak it runs south-south-eastwards to Meall an Aonaich (2345 ft.) as a great dividing ridge between the upper reaches of the River Cassley and the River Oykell. Southwards from Coinne-mheall, and separated from it by a low col or pass between the River Oykell and the River Traligill, lies the dome-shaped mass of Breabag (2670 ft.), which is continued south-eastwards to Sgonnan Mòr (2028 ft.). This elevated ground is bounded on the south by an east and west depression extending from Loch Ailsh by Lùban Cròma to Ledbeg.

The main rock groups that enter into the structure of the mountain ranges just described are the Lewisian Gneiss and the Cambrian Quartzite. The characteristic contour of the Lewisian Gneiss reappears in the displaced masses round the head of Loch Glencoul, in Ben More, and on Sgonnan Mòr. The quartzites, however, are the great mountain builders in this belt of complication. Though everywhere affected by numerous planes of disruption they form a protective covering or veneer above the underlying gneiss. Owing to their greater durability they retard the agents of denudation.

To the west of these mountain ranges and within the belt of complication there is a low-lying plateau, rising in places to the level of 1000 feet, extending from Achumore by the lower reaches of the Traligill to Allt nan Uamh (Burn of the Caves) south-east from Stronechrubie. This platform consists of thrust limestone and dolomite. Two prominent ridges, each 1500 feet in height, tower above it (Beinn an Fhuarain and Beinn nan Cnaimhseag). In the sequel it will be shown that these ridges are outliers (*Klippen*) of thrust materials above the Ben More thrust-plane, which there rest upon the Cambrian dolomite and limestone.

Another low-lying plateau, from 500 to 600 feet high on an average, runs in an east-south-east direction from Elphin by Loch Urigill and Loch Borrolan to the slopes of Cnoc na Glas Choille in the southern part of the area. It is largely covered with peat, but the available evidence indicates that it consists mainly of displaced masses of limestone and dolomite. Here and there this plain is modified by the occurrence of materials above the Ben More thrust-plane, giving

rise to more or less prominent features such as Cnoc na Glas Choille (1006 ft.), and Druim Poi Eòghainn.

As the observer enters the belt of complication in the southern part of Assynt his attention is arrested by the ridge of high ground extending from Cnoc na Sròine (1306 ft.) in an east-south-east direction towards Cnoc a' Chaoruinn. The steep declivity that bounds this ridge from Loch Borrolan by Ledbeg to the River Loyne is in marked contrast with the adjoining low-lying plateau. Here again we find a striking instance of the close relation between the geological structure and the surface contours, for the ridge is formed of plutonic igneous rocks.

Another type of scenery is to be found in the area lying to the east of the Moine thrust. It occurs in the north-eastern part of the region in the hills beyond the upper reaches of the River Cassley, and also in the south-east along the northern flank of the Cromalt Hills. The plateau is composed of crystalline schists which form less rocky contours than the Lewisian Gneiss to the west. Ribs of schist project through the peat and glacial deposits, but owing to the nature of the materials they give rise to softer outlines. Along the watershed between the River Cassley and the streams draining into the head of Loch Shin they form more or less prominent hills, such as Creag Riabhach (1238 ft.), Sròn Lom (1279 ft.), and Maol a' Bhealaidh (1673 ft.).

III. FORMATIONS AND ROCK GROUPS.

The explanation of geological signs and colours accompanying the model shows that the following formations occur within the area which it represents.

TABLE OF STRATA.

Recent.	Peat.	
	Alluvium.	
Cambrian.	Limestone and Dolomite	Marble.
		Eilean Dubh Group.
		Ghrudaidh Group.
	Serpulite Grit.	
	Fucoid Beds.	
	Quartzites	Pipe-rock.
		Basal false-bedded quartzites.
Torridonian.	Sandstones, grits, and conglomerates.	
Eastern Schists.	Quartzose schists, mica-schists, and mylonites.	
Lewisian.	Gneisses of the Fundamental Complex.	
	Dykes intrusive in the Fundamental Complex.	Dolerite.
		Peridotite.
Post-Cambrian Intrusive Igneous Rocks.	*Intruded before the movements.*	Granite, syenite, and borolanite.
		Felsite, porphyrite including Canisp porphyry.
	Intruded after the movements.	Lamprophyre.

DESCRIPTIONS OF ROCK GROUPS.

i. Lewisian Gneiss.

In the area represented by the model the Lewisian Gneiss may be separated into (1) a Fundamental Complex composed mainly of gneisses that have affinities with plutonic igneous products; (2) a series of igneous rocks intrusive in that complex in the form of dykes.

Fundamental Complex.—In the unmodified area west of the post-Cambrian displacements the dominant member of the Fundamental Complex is pyroxene-gneiss. In addition to the pyroxene, this type contains hornblende and biotite as original constituents. But the characteristic features of the group are the abundance of blue and semi-opalescent quartz, the carious weathering of the surface due to the decomposition of the felspar and ferro-magnesian constituents, and the projecting network of quartz. In the field a gradation can frequently be traced from a type rich in ferro-magnesian minerals to a variety composed mainly of quartz and felspar. It is further observable that the pyroxene-gneiss with hornblende and biotite passes imperceptibly into grey hornblende-gneiss with biotite, containing similar blue quartz. The secondary hornblende replaces the augite in such an irregular manner that the rock may pass, in a short distance, from a pyroxenic to a hornblendic gneiss. There is considerable variation in the strike of the unmodified gneisses of the Fundamental Complex. They are thrown into gentle folds, whose long axes run in various directions, as, for example, towards the N.E., N.N.E., N.W., W.N.W., and W.

Pre-Torridonian Dykes intrusive in the Fundamental Complex.—West of the post-Cambrian displacements there is a typical development of the basic and ultra-basic dykes which were intruded in the Fundamental Complex in pre-Torridonian time. The basic group is most abundant, and the varietal types included in it are remarkable. Thus on the north shore of Loch Assynt at Rudha na Doire Cuilinn, four miles W.N.W. of Inchnadamff, there is a dyke of olivine-norite. Again the dyke that crosses the small promontories north-west of Rudha na Doire Cuilinn ranges from a hyperite and enstatite-diabase in the centre to an epidiorite or epidote-amphibolite at the margin where there are signs of deformation. Evidence of similar rapid variation is furnished by the massive dyke, 50–70 yards broad, that follows the south shore of Loch Glencoul, east from the mouth of Unapool Burn. It includes rocks described as diabase, gabbro, and epidote-amphibolite.

The dykes of epidiorite or hornblende-plagioclase-rocks are separable into two groups, according to the presence or absence of igneous structure. An example of the igneous structure, with lath-shaped interstitial felspars, occurs in the dyke that runs immediately below the road and close to the shore of Loch Assynt, about four miles west from Inchnadamff. The typical rocks of the group in which igneous structure is not apparent are essentially composed of plagioclase and hornblende, with some quartz. These include a large number of the dykes of the area.

The intrusive character of the basic dykes is clearly displayed.

They rise along well defined fissures with more or less vertical walls. They truncate the planes of mineral banding of the original gneisses, and they have chilled margins. Their general trend is W.N.W. or north-west.

The ultra-basic dykes are composed of olivine and augite, with some reddish brown biotite. Their general direction is nearly east and west. Owing to their ultra-basic character they frequently decompose and give rise to long narrow slacks or clefts. In the ground between Loch Assynt and Suilven there is ample evidence that the picrite dykes intersect the basic series, and are therefore of later date.

On the north shore of Loch Glencoul, near the entrance to the sea-loch, there is a dyke of microcline-mica-rock which trends in a north-east direction. It passes through the hill of Aird da Loch to Loch Glendhu. It seems to cross several basic dykes, and is accompanied by a fault that shifts these intrusions.

Pre-Torridonian Movements.—In the area represented by the model there is clear evidence of the modification of the original gneisses and the dykes by pre-Torridonian movements. These produced definite lines of disruption or thrust-planes and well-marked zones or belts of secondary foliation which run in various directions. One of these, trending W.N.W. and E.S.E. that is more or less parallel with the basic dykes, is well developed in the tract between Canisp and Suilven.

The modifications of the gneiss are here remarkable. The pyroxene-gneiss is folded and dragged into parallelism with the lines of movement. The opalescence of the quartz disappears, biotite is developed, and the felspars are granulitised. Within the shear-zone the reconstruction of the rock is complete, and it appears as a fine granulitic micaceous gneiss whose foliation planes dip at high angles. Occasionally a lenticle or phacoid of the modified pyroxene-hornblende-gneiss appears within the narrow belt of reconstructed gneiss showing the intermediate stage of change.

The alteration of the dykes in the Canisp Forest is no less conspicuous. The various stages in the conversion of a basic dyke into hornblende-schist are laid bare. Sometimes marginal strips of hornblende-schist occur at the edges of a dyke while the interior remains massive. Sometimes a lenticular or phacoidal structure is met with, when isolated portions of crushed basic rock are surrounded by wisps and bands of hornblende-schist. Eventually when the shear-planes coalesce the basic dykes are entirely converted into hornblende-schist, with a platy parallel foliation and abundant biotite on the divisional planes.

All these movements, resulting in the modification of the gneiss and dykes, must have been completed before the deposition of the Torridon Sandstone. The lines of disruption can be traced up to the base of the Torridon Sandstone on Canisp, but they do not enter the sandstone. They pass under the escarpment of Cambrian quartzite between Canisp and Suilven. Pebbles of the reconstructed granulitic gneiss and of hornblende-schist are found in the basal Torridon breccias in Canisp and at the east end of the Suilven outlier.

Inliers of Lewisian Gneiss above the Glencoul and Ben More Thrust-planes.—Detached masses of Lewisian Gneiss appear in the areas affected by the post-Cambrian movements. Of these inliers, the

largest occur on the mountains around the head of Loch Glencoul, on Ben More, and Sgonnan Mòr. Smaller areas are found in Glas Bheinn and Beinn an Fhurain, north and east of Inchnadamff, on the hill between Ledbeg and Càm Loch, and in other places.

One important feature connected with the thrust mass above the Glencoul thrust-plane is that the rocks composing it differ lithologically from those in the undisturbed area lying immediately to the west of them. The hornblende-biotite-gneisses, for example, contain many thick red pegmatites, which in the unthrust gneiss are rare. On the other hand, while basic dykes of pre-Torridonian age are numerous in the undisturbed area to the west, they appear to be absent from the thrust gneiss beyond half a mile north from Loch Glencoul. *In brief, the type of Lewisian Gneiss in the unthrust region which most resembles that of the Glencoul thrust mass lies several miles to the north of Kylesku.*

The inliers of Lewisian Gneiss farther south, especially the masses on Ben More and Sgonnan Mòr, include well marked types, which are characteristic of the Fundamental Complex between Scourie and Lochinver. These comprise pyroxenites and hornblendites, grey pyroxene-gneiss and hornblende-gneiss with blue quartz, and hornblende-biotite-gneiss. The general strike of the Lewisian gneisses in the Ben More inliers is N.N.W. and S.S.E., and the early foliation is quite apparent. In all the corries on the north-east face of Ben More, in Corrie Mhadaidh, north-west of Ben More and on Sgonnan Mòr, the original structures of the early basic masses can be readily recognised.

Numerous dykes occur in the gneiss above the Ben More thrust-plane, as shown in the model. Here they still preserve those features which are so characteristically developed in the undisturbed area to the west of the post-Cambrian belt of complication. The basic types have the same north-westerly trend, and the ultrabasic varieties run nearly east and west. Most of these intrusions consist of massive epidiorite, in some cases reaching 100 yards in breadth, and usually showing strips of hornblende-schist along their margins. Some examples of the later picrite dykes have been recorded, as, for instance, on the plateau west from Dhu Loch Beag, about three miles up the Oykell valley from Kinlochailsh, and also on the south-west face of Sgonnan Mòr close by the unconformable base line of the Torridon Sandstone.

In those localities where the Lewisian Gneiss immediately overlies the Glencoul and Ben More thrust-planes, the rocks composing it have been sheared and rendered schistose, the planes of schistosity being parallel with the post-Cambrian planes of movement. Not far to the east of these thrust-planes the gneiss resumes its N.N.W. and S.S.E. strike. Similar deformation is observable in the thrust Lewisian Gneiss along its line of junction with the Torridon and Cambrian strata. This feature is conspicuously developed in the great cliff on the south face of Ben More.

ii. Torridonian Formation.

Before the deposition of the Torridonian sediments the Lewisian Gneiss formed a land surface, which was subjected to prolonged

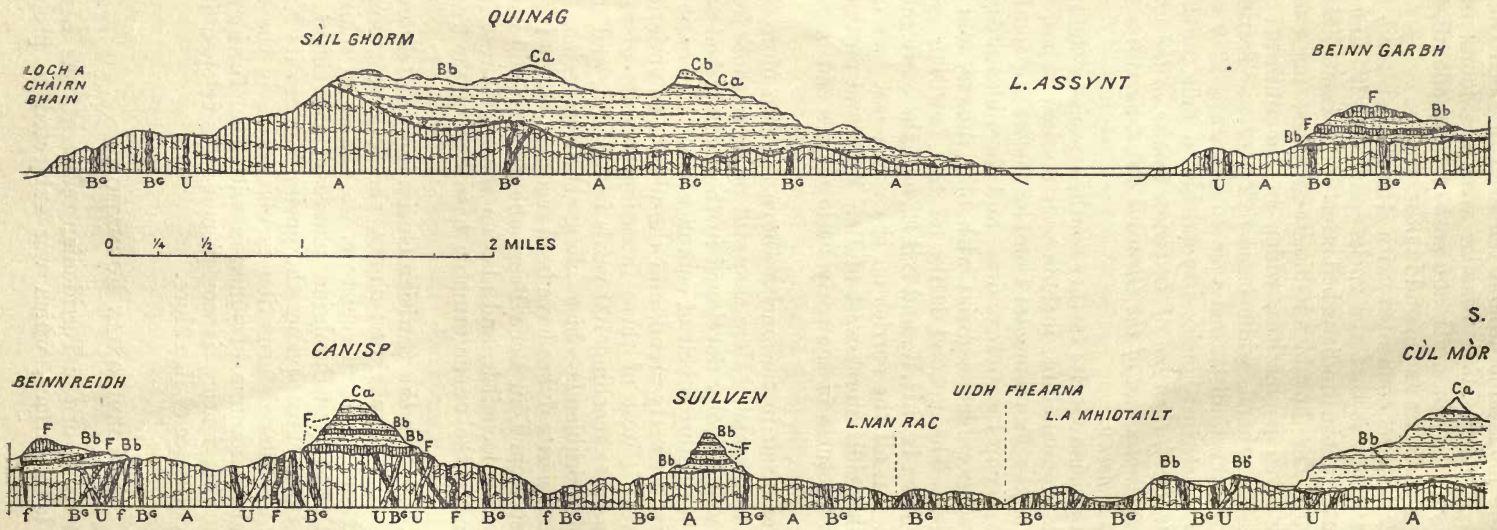

FIG. 1.—Section from Loch A'Chàirn Bhàin to Cùl Mòr.

A. Lewisian. Bb. Torridonian. Ca. Cambrian Quartzite (basal). Cb. Cambrian Quartzite (pipe-rock). F. Porphyrite (Canisp porphyry).
f. Faults.
Bg = Basic.
U = Ultrabasic. } Pre-Torridonian Dykes.

denudation. Within the area represented by the model there is clear evidence that this primeval land surface had developed an undulating contour with minor hills and hollows before the Torridon Sandstone was laid down. Everywhere there is a marked unconformability between the two rock groups. Indeed, it is one of the most striking features in the North-West Highlands (Fig. 1).

The Torridonian sediments exposed in the range of isolated hills, comprising Quinag, Beinn Gharbh, Suilven, and Cùl Mòr, belong to the Applecross group, which forms the middle division of this system. The strata consist mainly of coarse-grained felspathic grits and sandstones, with occasional thin intercalations of fine-grained micaceous shale and sandstone. Coarse angular breccia occurs as a local base, and in places a band of conglomerate with well-rounded pebbles occupies that position. Scattered pebbles are to be found throughout the grits and sandstones, and false-bedding is characteristically developed. The dominant felspar in the coarse sediments is microcline in fresh preservation—a mineral which only occurs in any abundance in that part of the Lewisian Gneiss plateau extending from Cape Wrath to Loch Laxford. The pebbles that are so abundant in the arkose series are composed of sedimentary, metamorphic, and igneous rocks which are not now found within the Lewisian area. The local basal breccias contain recognisable fragments of Lewisian Gneiss, but the bulk of the sediments are of foreign origin.

It is worthy of note, as throwing some light on the conditions of deposition that some wind-eroded pebbles (*dreikanter*) have been detected in the arkose series of Quinag.

The total thickness of Torridonian strata on Spidean Còinich (Quinag) is 1900 ft. About 400 ft. above the base, on the southern slope of that hill, conglomerates with well-rounded pebbles, like the conglomerates of the Cape Wrath area, are laid bare. The dip of the arkose series north of Loch Assynt is towards the east-south-east at angles varying from 4° to 8°. On Beinn Garbh, Beinn Reidh, Canisp, and Suilven the false-bedded grits and sandstones have been injected by sheets or sills of porphyry of post-Cambrian age. In Canisp they range from 20 to 60 ft. in thickness, and are more or less parallel to the bedding planes of the strata. On these hills the Torridonian sediments dip towards the east, east-south-east, or south-east at angles which, as a rule, do not exceed 6°.

Along the northern base of Cùl Mòr, as in Suilven and Canisp, there is a well-marked basal breccia, composed of fragments of the underlying gneiss. Where the Torridonian sediments have been recently removed, the gneiss is generally epidotic at, and for some distance below, the surface. Above these basal breccias there rises a great pile of false-bedded purple grits and sandstones, upwards of 2,000 ft. in thickness, with a general inclination in a southerly direction at very low angles.

Inliers of Torridon Sandstone above the Ben More thrust-plane.—Above the Ben More thrust-plane recognisable masses of Torridon Sandstone have been found. They appear on Ben More, on Sgonnan Mòr, on Beinn nan Cnaimhseag, Beinn an Fhuarain, and to the south of Loch Urigill, near Am Pollan. In all these localities, with one exception, the Torridonian sediments consist of a series of grits and sandstones resembling those of the Applecross group. But on the south-west slope of Sgonnan Mòr and in the Oykell valley there is a considerable thick-

ness of fine-grained sandstones, flagstones, and shales with dark seams like the Diabaig group or lowest division of the Torridon Sandstone. These strata immediately overlie, in inverted order, the basal conglomerate in contact with the thrust Lewisian Gneiss. They have not been met with in the undisturbed region between Quinag and Cùl Mòr to the west. At the base of the displaced masses of Torridon Sandstone there is frequently a lenticular band of conglomerate with well-rounded pebbles of quartz-rock, gneiss, pegmatite, and other materials. Where these strata have been subjected to mechanical movements, especially near the thrust-planes, they have undergone considerable modifications.

In the case of the basal conglomerate or "button stone," the pebbles have been crushed, flattened, and elongated in the direction of movement. The gritty matrix has become schistose, winding round the drawn-out pebbles in wavy lines. This type of deformation is to be found in the basal conglomerate, where it underlies the Lewisian Gneiss in the Oykell valley, and where it overlies that rock in Corrie a' Mhadaidh on the north side of Ben More.

The Torridon grits, sandstones, and shales in Corrie a' Mhadaidh have been cleaved, the cleavage planes dipping towards the east-south-east—that is, more or less parallel with the plane of the Ben More thrust, while the original lines of bedding are there inclined towards the west-north-west. Owing to the variable nature of the Torridonian strata, the cleavage is unequally distributed, the coarse grits being less distinctly cleaved and the planes being more highly inclined in them than in the finer sandstones and shales. In addition to the cleavage, sericite has been developed in some of the beds, and, along the finer bands between the grits, lenticular veins of pegmatite, consisting mainly of quartzo-felspathic materials, occur more or less parallel with the new schistose planes.

iii. Cambrian Formation.

In the area represented by the model there is clear evidence of extensive denudation of the Lewisian Gneiss and Torridonian strata before the deposition of the Cambrian sediments. Instead of an undulating land surface of hill and valley the pre-Cambrian rocks were reduced to an uniform plane probably of marine denudation. The Cambrian basal beds rest in some places on the Lewisian Gneiss, in others on the Torridon Sandstone, and, in a few localities, on both. Where the Lewisian Gneiss immediately underlies the Cambrian quartzites it has undergone a peculiar phase of decomposition; in particular, the felspar has been changed into agalmatolite. Where the Cambrian sediments lie upon Torridonian strata the latter are bleached and the felspars are kaolinised, thus contrasting with the normal development of the red sandstone. Lastly a fine conglomerate or pebbly grit, from a few inches to two or more feet in thickness, occurs at the base of the quartzites.

In Assynt the red sandstones and grits are generally inclined to the E.S.E. at lower angles than the overlying Cambrian quartzites. Hence they are transgressed, bed after bed, by the basal quartzites, which come to rest directly on the Lewisian Gneiss. This double unconformability is clearly displayed on the slopes of Beinn Gharbh,

along the southern shore of Loch Assynt and on Canisp (see Figs. 7 and 11). Confirmatory evidence of the unconformability between the Cambrian strata and the older rocks is to be found in the rock-masses displaced by the post-Cambrian movements. It has been further proved that the original eastern limit of the red sandstones lay far to the east of the areas not affected by these movements. In the disrupted materials on Sgonnan Mòr there are representatives of the Applecross and Diabaig groups of the Torridon Sandstone with a conglomerate at their base. The Cambrian quartzites there pass transgressively across the red sandstones till they rest directly on the Lewisian Gneiss.

From these data it may be inferred that during the interval which elapsed between the deposition of the Torridon Sandstones and Cambrian quartzites, the former were thrown into a series of gentle folds; a vast thickness of them was then removed, so as to expose the Lewisian rocks over wide areas; and the surface of the region was reduced to a fairly uniform plane, as shown in the accompanying diagram.

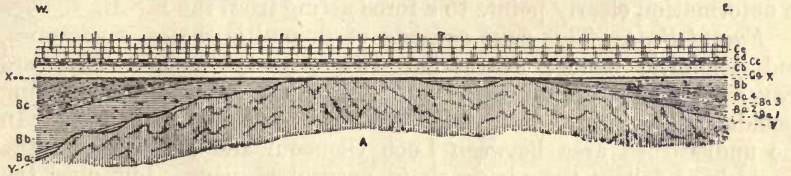

FIG. 2.—Diagram showing the formation of Outliers of Torridon Sandstone by folding and denudation in Post-Torridonian and Pre-Cambrian time.

A. Lewisian Gneiss. Ba.—Bc. Torridonian. Ca.—Ce. Cambrian. Y. Pre-Torridonian surface of erosion. X. Pre-Cambrian plane of marine denudation.

Quartzites.—This series varies from 500 to 600 ft. in thickness, and forms two well-marked subdivisions. The lower one is composed of false-bedded flaggy grits and quartzites, containing grains of quartz and felspar. At the base there is a fine brecciated conglomerate or pebbly grit. The upper or pipe-rock subdivision consists of fine-grained quartzites, perforated by vertical worm casts and burrows (*Scolithus*). These have been subdivided into five sub-zones, each distinguished by its peculiar variety of pipe. Their distinctive features and thicknesses are given in the subjoined table.

			Ft.
SUB-ZONE	5.	Massive purple grit with vertical pipes . . .	36
,,	4.	Flaggy quartzites with pink and white seams, the pipes usually of a different colour from the matrix; the lower beds varying from 2 to 6 inches in thickness . .	48
,,	3.	Massive fine-grained white quartzite with rusty surface .	15
		Flaggy quartzites, sometimes false-bedded, with certain bands containing large pipes 3 or 4 inches across, and passing downwards into white pipe-rock . . .	75
,,	2.	Massive quartzite in bands from 1 to 3 ft. thick, with small pipes about half an inch in diameter . . .	74
,,	1.	Massive white saccharoidal quartzite beds, averaging from 3 to 4 ft. in thickness, with small pipes about ⅛-inch in diameter	27
			275

Along the eastern slopes of Quinag, Beinn Gharbh, Canisp, and Cùl

Mòr the quartzites are inclined in an east-south-east direction, at angles varying generally from 10° to 18°. They form the long dip-slopes represented in the model immediately to the west of the post-Cambrian displacements.

As already indicated, the quartzites cover large areas along the eastern mountain ranges within the belt of complication. South of the mountainous region, outliers of quartzite, sometimes with a core of Lewisian Gneiss, are found at various localities—as, for instance, between Càm Loch and Loch Urigill, at Am Pollan, south of Loch Urigill, and on Cnoc na Glas Choille. In the thrust masses beneath and close to the Moine thrust-plane the members of this series have undergone considerable modifications. In the extreme stage of deformation both subdivisions have been considerably reduced in thickness. The basal quartzites become hard, compact quartz-schists in which the grains of quartz and felspar have been drawn out. The pipes of the upper zone, which, in the undisturbed area to the west, are always perpendicular to the bedding planes, are bent over towards the W.N.W., and flattened like strips of paper. This type of deformation clearly points to a force acting from the E.S.E.

Fucoid-Beds.—This zone consists of dolomitic shales, mudstones, and dolomitic bands, weathering with a rusty colour. They are traversed by numerous worm-casts usually flattened and resembling fucoidal impressions, and yield *Olenellus*, *Salterella*, *Hyolithes*. In the undisturbed area between Loch Glencoul and Loch Assynt the fucoid-beds follow the pipe-rock in natural sequence, but over the greater part of this distance only the lower portion of the zone lies to the west of the first line of displacement. On the north shore of Loch Assynt, however, and in the ground immediately to the north thereof, the most westerly thrust appears in the basal dolomites (Ghrudaidh group). At these localities the whole of the zone is displayed, and, within three feet of the top, fragments of *Olenellus Lapworthi* have been obtained in soft cream-coloured shale. Remains of *Olenellus* have also been found at the top of the zone near the base of the Knockan cliff at the south end of the area, and at other localities.

Serpulite-Grit.—This zone, measuring about 30 ft. in thickness, consists of a massive band of quartzite and grit at the base, passing upwards into carious dolomitic grit, crowded in patches with *Salterella*. It usually gives rise to an escarpment between the underlying fucoid-beds and overlying basal dolomite. One of its characteristic features is the presence of pipes or worm-casts which sometimes reach the diameter of nearly an inch. They can be traced vertically through the rock for the length of more than a yard, until they end on the upper carious-weathering surface of the grit in cup-shaped depressions several inches across. The small tubicolar *Salterella*, the *Serpulites Maccullochii* of Salter, though more abundant near the top, is usually to be found scattered throughout the whole zone.

A glance at the model will show that the fucoid-beds and serpulite-grit have a wide distribution within the belt of complication. They cover broad areas in the hollow along Allt Sgiathaig, south-east of Quinag; they extend up the Traligill valley; they appear on the crest and western slopes of Breabag, at Loch Ailsh, and on the west declivity of Cnoc a' Chaoruinn.

Limestone and Dolomite.—In the area represented by the model

only the three lower groups of the Cambrian Calcareous Series are represented, viz., the Ghrudaidh, the Eilean Dubh, and Sailmhor divisions. The lowest group consists of dark leaden-coloured dolomites, occasionally mottled, alternating near the top with white limestone. At the base there is a thin band of dolomite charged with *Salterella pulchella*, and a similar band occurs about 30 ft. higher up. The Eilean Dubh group is composed of fine-grained white, flaggy, argillaceous dolomites and limestones, with chert bands. The members of the third division (Sailmhor) consist of massive crystalline granular dolomites, containing dark worm-castings set in a grey matrix. No fossils have been found in the Eilean Dubh and Sailmhor groups in Assynt.

The model reveals the wide development of the limestones and dolomites in the belt of complication in Assynt. From the base of the western slope of Glas Bheinn they stretch southwards by Achumore to the Traligill and Allt nan Uamh, two and a half miles south from Inchnadamff. The highest beds are exposed on the plateau a mile and a half south-east from Inchnadamff Hotel. They likewise extend for a distance of four miles across the peaty moorland south-east from Elphin.

iv. Post-Cambrian Igneous Rocks older than the Movements.

The crystalline rocks illustrating this phase of igneous activity occur in Assynt (1) as plutonic masses, (2) as intrusive sheets or sills, and (3) as dykes.

Plutonic Masses.—A glance at the model will show the great development of the plutonic mass of Cnoc na Sròine and Loch Borrolan. It covers an area five miles in extent from Ledbeg eastwards to a point near the road leading to Loch Ailsh. Along the north-western and western margin of the plutonic rocks near Ledmore, Ledbeg, and Cnoc an Leathaid Bhig their relations to the altered Cambrian dolomite are complicated by the occurrence of various outliers of materials resting above the Ben More thrust-plane, once continuous, but now forming isolated patches, which cover portions both of the igneous rocks and the marble. This mass includes granite, quartz-syenite, melanite-syenite, nepheline-syenite, and borolanite. Though the materials are generally massive, a distinctly foliated type of borolanite appears to the east of Aultnaccalgach Inn in a small stream (Aultivullin) which drains Loch a' Mheallian and flows southwards into the Allt an Lòin Dhuibh. The foliation planes dip towards the east at an angle of 15°, thus coinciding with the general inclination of the post-Cambrian planes of movement.

Sills and Dykes.—Reference has already been made to the intrusive sheets or sills in the Torridon Sandstone on Beinn Gharbh, on Canisp, and on Suilven. The well-known albite-porphyrite of Canisp rises from the old platform of Lewisian Gneiss on the west face of that mountain, thence passes upwards into the overlying red sandstones, and spreads along the bedding planes of the strata. It is not improbable that the porphyrite sills on Suilven, now isolated by denudation, may have been originally continuous with those on Canisp (Fig. 1). The sill-like character of these intrusions is clearly displayed in

the Cambrian area represented by the model where the sheets are more or less confined to certain horizons. In that region the sills vary in thickness from 10 to 50 ft. The most persistent are those in the basal quartzites, in the third sub-zone of the pipe-rock, in the fucoid-beds, and near the base of the Ghrudaidh dolomites. One sill, which has a wide extension on the Ben More range, has been intruded at the junction between the quartzites and Lewisian Gneiss where the Torridon Sandstones have been removed. The materials of these intrusive sheets consist of diorites, including vogesites and spessartites, albite-porphyrites, and ægirine-felsites. The more basic varieties (diorites) are associated with the fucoid-beds and overlying dolomites, while the more acid types appear in the quartzites.

On referring to the model it will be seen that these sills occupy their respective horizons in the piled-up Cambrian strata west of the Glencoul and Ben More thrusts, in the displaced masses above these great disruption planes, and close to the Moine thrust. The sills, as well as the strata which they traverse, have been truncated by the major and minor lines of displacement, and, in certain cases, the intrusive sheets become schistose, the planes of foliation being parallel to those produced by the post-Cambrian movements.

A sheet of igneous material closely related to the Loch Borrolan mass appears above the Ben More thrust, near Kinlochailsh in the Oykell valley. It is separated from the displaced Lewisian Gneiss and Cambrian quartzites by a thrust.

The dykes are comparatively rare. Two examples of orthophyre, which Dr. Teall regards as the dyke phase of the syenite magma, occur on Sgonnan Mòr. A dyke of the Canisp porphyrite pierces both divisions of the quartzite on the south side of that hill, and has been traced across the plateau of Lewisian Gneiss.

Contact Metamorphism produced by the plutonic mass of Cnoc na Sròine.—The most characteristic feature is the production of marbles where the Cambrian calcareous series has been invaded by the plutonic masses. The minerals present in the altered rocks are calcite, dolomite, brucite, diopside, forsterite, serpentine, mica, and tremolite. Dr. Teall's general conclusions * are that the marbles of Assynt are, for the most part, altered dolomites, and that the alteration has been accompanied by dedolomitisation due either (1) to the development of magnesian silicates such as forsterite and tremolite, or (2) to the formation of periclase or brucite.

v. Eastern Schists.

This group includes the great series of crystalline schistose rocks which lie upon the Moine thrust-plane—the most easterly of the great post-Cambrian displacements. Where the plane of this thrust is clearly exposed, as at Knockan and the Stack of Glencoul, the western limit of these schists is easily defined. But it is often extremely difficult to determine the precise position of this plane of disruption. Owing to the development of mylonised rocks about its horizon, the actual " sole " or thrust-plane is apt to be lost among the crushed and

* " The Geological Structure of the North-West Highlands of Scotland " (*Mem. Geol. Surv.*), p. 453, 1907.

rolled-out materials which have been driven along in the line of movement.

In the area represented by the model the Eastern Schists include (1) mylonised rocks, (2) puckered grey schists, and (3) granulitic siliceous flagstones with thin mica-schists. The mylonised rocks have been derived from different types of Lewisian Gneiss and pegmatites, from the Torridon Sandstone and Cambrian Quartzite. The puckered schists are extremely fine-grained. They are highly contorted along axial planes which dip east-south-east—that is, more or less parallel to the plane of the Moine thrust. The granulitic siliceous schists are usually flaggy, with muscovite and less frequently biotite along their divisional planes. Augen of quartz and felspar may represent the remnants of original clastic grains.

South-east of Glencoul intrusions of foliated granite appear in the Eastern Schists, and have their foliation planes parallel to those in the adjoining siliceous schists. Similar evidence is obtained in the area east of Loch Ailsh and near the Knockan, where sills of sheared porphyrite and syenite-porphyry are intercalated among these schists. In the Knockan Burn, about 100 yards up that stream from the Moine thrust-plane, the sediments into which the sills have been intruded are not much deformed. One specimen is a mylonised arkose in which the pebbly structure is not yet destroyed. These metamorphosed igneous sills so closely resemble some of the intrusive sheets among the Cambrian rocks of Assynt, which were injected before the post-Cambrian movements, as to justify the inference that, whatever may have been the origin of the Moine schists, the dominant structures impressed on them and on the porphyritic sills must have been produced by the same movements.

IV. GEOLOGICAL STRUCTURE OF THE AREA AFFECTED BY POST-CAMBRIAN MOVEMENTS IN ASSYNT.

The various types of structure due to the post-Cambrian movements within the belt of complication represented by the model have definite relations to each other in the field, and occur in consecutive order from west to east. From this point of view, the structures may be arranged in two divisions ; (*a*) those which occur in advance of, or to the west of, the great lines of disruption ; (*b*) those immediately associated with each of the powerful thrusts which have produced extensive displacements of the strata.

i. Structures in Advance of the Great Thrusts.

Imbricate Structure.—This type is generally confined to the belt of complication that intervenes between the undisturbed area to the west and the outcrop of the great thrust-planes to the east. In this system the Cambrian zones are repeated by minor thrusts without incipient folding. Lower zones are made to rest on higher beds by means of reversed faults, the latter being inclined at a slightly higher angle than the dip of the strata. Save in exceptional instances, the beds between each reversed fault preserve their normal order of succession, and have a persistent dip to the E.S.E., thus furnishing an example of imbricate

structure (*Schuppen Struktur*). The slices of strata thus repeated have been driven westwards by major thrusts along planes which truncate the overlying reversed faults. This type has a remarkable

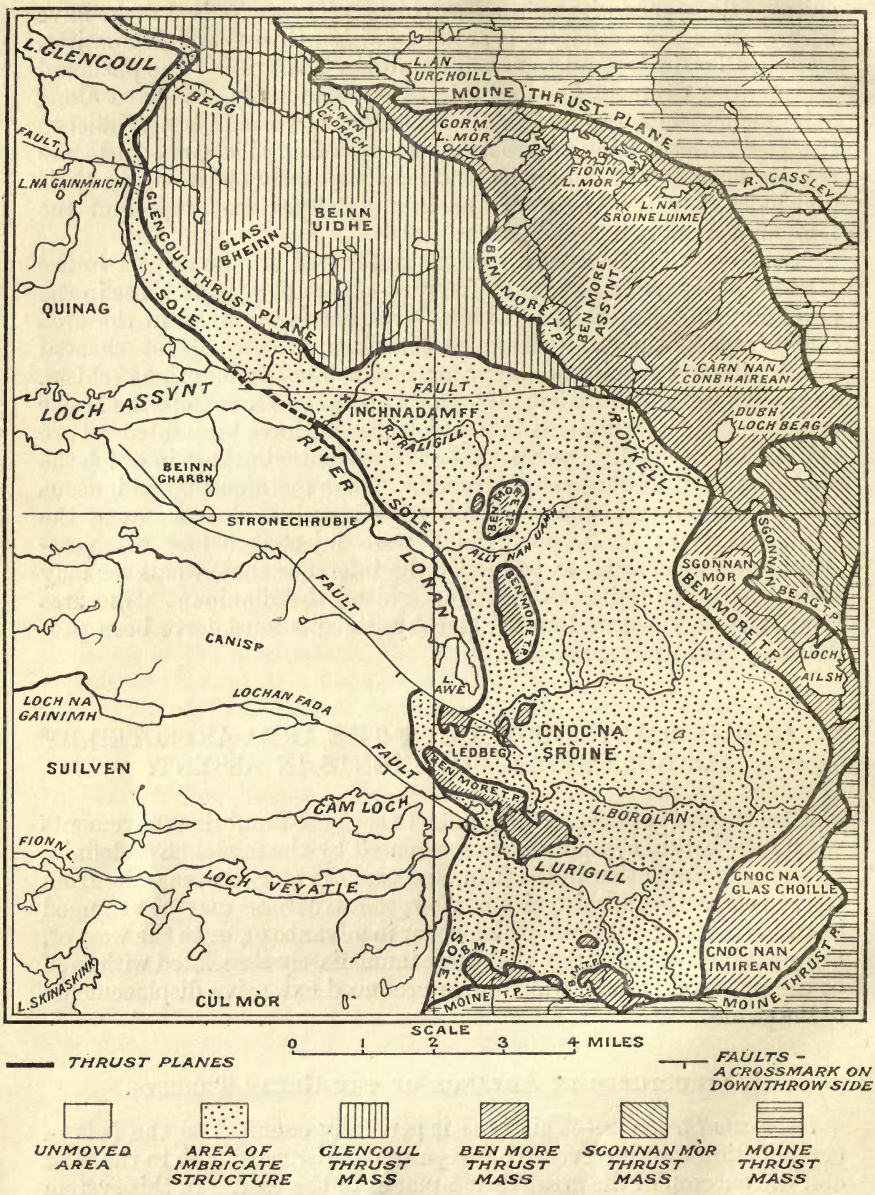

FIG. 3.—Sketch-map of Thrust masses in the area represented by the model.

development on the north and south shores of Loch Glencoul, where the strata repeated by this system of reversed faults consist of fucoid-beds, serpulite-grit, and basal dolomite, the whole thickness of sediments not exceeding 100 feet.

One of the best sections for studying this structure in the field is on the hill slope on the south side of Loch Glencoul below Cnoc na Creige (Fig. 4), where the observer passes from the undisturbed Cambrian quartzites and fucoid-beds across the narrow belt of imbricate structure to the Glencoul thrust which has brought westwards a great mass of Lewisian Gneiss. It is also clearly exposed on the north side of Loch Glencoul beneath the Glencoul thrust-plane.

This type of structure extends over a considerable area (see Fig. 3 and the horizontal sections at the sides of the model), but owing to the covering of peat and drift the piled-up masses in advance of the great lines of displacement are not clearly exposed. Near the outcrop of the Moine thrust folding accompanies the minor thrusts in the belt of imbricate structure.

ii. Structures characteristic of the Great Thrusts.

Three powerful lines of disruption traverse the area represented by the model, viz. : the Glencoul, the Ben More, and the Moine thrusts,

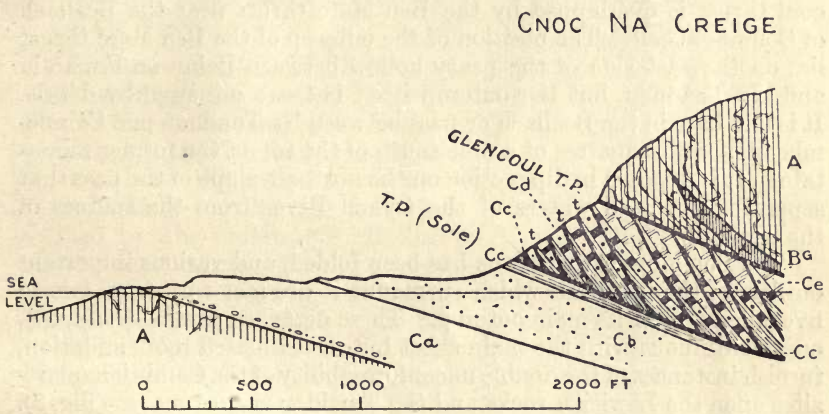

Fig. 4.—Section from south shore of Loch Glencoul to Cnoc na Creige.

A. Lewisian Gneiss. Bg. Dykes in gneiss. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce. Limestone (Cambrian) T. P. Thrusts.

which follow each other in definite order from west to east (see model and Fig. 3). The outcrops of these great thrust-planes resemble boundary lines between unconformable formations because (1) there is always a complete discordance between the strata lying above and below the planes of disruption, and (2) each successive thrust may be overlapped in turn by a higher one. These features are clearly displayed in Assynt.

Glencoul Thrust.—This great line of disruption—the most westerly of the series—brings forward the Lewisian Gneiss, covered unconformably by Cambrian strata. No representatives of the Torridon Sandstone occur among the displaced materials driven westwards by the Glencoul thrust. One of the remarkable features of this line of movement is the vast thickness of the slice of the old Archæan floor that has been superimposed on the piled-up Cambrian strata beneath.

Near Glencoul it must be, at least, 1500 ft. thick, and in that region it has borne westward all the Cambrian zones in succession from the false-bedded quartzites up to the dolomite and limestone. When the Glencoul line of movement is traced southwards towards Inchnadamff, the thin veneer of quartzites on the crest of Glas Bheinn is found to fold over and to buckle under the western face of displaced gneiss, and the quartzites there rest in inverted order on that thrust-plane.

Ben More Thrust.—Important structural features appear above this plane of movement. Here we find a great slice of Lewisian rocks covered unconformably by Torridon Sandstone with the double unconformability of the Cambrian quartzites upon the Lewisian Gneiss and Torridonian strata. The slice of Lewisian rocks cannot be less than 1500 ft. in thickness on Ben More, where it forms a great dome-shaped flexure with the uncomformable sediments arranged in inverted order beneath the displaced gneiss. On the eastern ridge of Ben More the thin covering of quartzites on the crest of the fold has been largely removed, but on Sgonnan Mòr, and particularly on its southern slope, the arch is seen in a less advanced stage of decay.

On referring to the model and Fig. 3 it will be seen that the Glencoul thrust is overlapped by the Ben More thrust near the Beallach of Coinne-mheall. The position of the outcrop of the Ben More thrust lies on the east side of the peaty hollow between Beinn an Fhuarain and Na Tuadhan, but the outcrop itself is there obscured by débris. It is laid bare in the Beallach or pass between Na Tuadhan and Coinne-mheall, about a quarter of a mile south of the top of the former mountain. It is exposed in dip section on the northern slope of the pass that separates the head waters of the Oykell River from the sources of the Traligill.

The Ben More thrust-plane has been folded, and various important outliers of the materials which surmount it are met with from two to five miles west of its main outcrop. These detached masses (*Klippen*), once continuous with the main sheet but now isolated by denudation, furnish instances of the double unconformability of the Cambrian quartzites upon the Lewisian rocks and the Torridon Sandstone (see Fig. 3). The most prominent of these masses occur on Beinn nan Cnaimhseag, three miles south-east from Inchnadamff, on Beinn an Fhuarain, east of Loch Awe, on the ground between Ledbeg and Càm Loch, and on the moor to the south of Loch Urigill.

On the eastern slope of Sgonnan Mòr and in the Oykell valley north of Loch Ailsh a thrust of minor importance bounds the sheet of syenite, to which reference has already been made. In Fig. 3 it is named the Sgonnan Beag thrust.

Moine Thrust.—This line of disruption—the most easterly of the series—is perhaps the most important structural feature produced by the post-Cambrian movements in the North-West Highlands. It differs from all others to the west in the crystalline condition of the materials which it has transported westwards. A marked characteristic of the Eastern Schists is seen in their double system of folding, evidently produced by the same series of earth-stresses; one set of flexures trending N.N.E. and S.S.W. in accordance with the general strike of the rock groups, and the other set W.N.W. and E.S.E. in the line of direction of the post-Cambrian movements. Their most characteristic feature in Assynt is the extraordinary overlap across all under-

lying thrusts and displaced masses till they rest directly on the undisturbed Cambrian rocks to the west (see the model and Fig. 3). The extreme narrowness of the belt of complication south of Knockan is due to the transgression of the Moine schists along that thrust-plane. The broad belt of thrust materials in the area represented by the model must have been originally covered by the Eastern Schists. Their removal by denudation has laid bare the series of complicated structures produced by the post-Cambrian movements.

iii. Horizontal Sections showing the Geological Structure of the Area represented by the Model.

Tectonics of Glencoul District.—The accompanying section (Fig. 5) clearly illustrates the great transgression of the displaced Lewisian Gneiss above the Glencoul thrust-plane, which was figured and described by Dr. Callaway.* It also shows the superposition of the gneiss upon the piled-up Cambrian strata—a feature which can be studied in detail on the north side of that sea-loch (see the section at the edge of the model north of Loch Glencoul).

At the western limit of the section the undisturbed Lewisian Gneiss (A) is covered unconformably by the Cambrian basal quartzites (Ca), followed in normal sequence by the pipe-rock (Cb), and the fucoid-beds (Cc). Here the succession is interrupted by the first thrust-plane or "sole" along which have been driven slices of fucoid-beds, serpulite-grit (Cd), and basal dolomite (Ce I). This imbricate structure (*Schuppen Struktur*) can be followed for a distance of three-quarters of a mile to the head of Loch Glencoul. Towards the west this zone of piled-

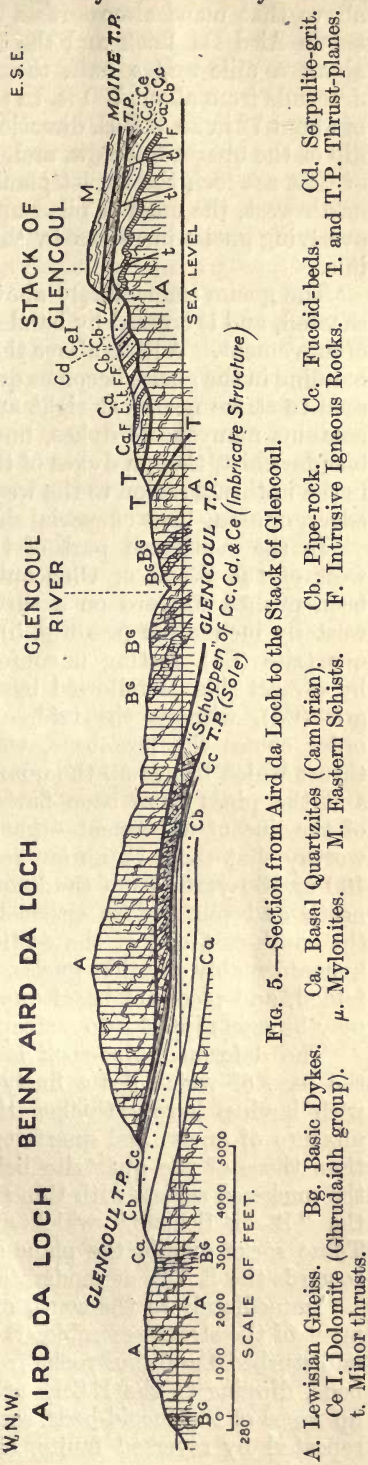

Fig. 5.—Section from Aird da Loch to the Stack of Glencoul.

A. Lewisian Gneiss. Bg. Basic Dykes. Ca. Basal Quartzites (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit.
Ce I. Dolomite (Ghrudaidh group). μ. Mylonites. M. Eastern Schists. F. Intrusive Igneous Rocks. T. and T.P. Thrust-planes.
t. Minor thrusts.

* *Quart. Journ. Geol. Soc.* vol. xxxix. 1883, p. 373.

up strata is overlapped by the Glencoul thrust, and the Lewisian Gneiss above that plane almost rests on the undisturbed fucoid-beds. Between Aird Da Loch and the head of Loch Glencoul, a distance of about a mile and a half, the outcrop of the Glencoul thrust-plane descends from about 700 ft. to the sea-level, with a general inclination of about 7° in an E.S.E. direction. This slope is less than the average dip of the quartzite below, and, as for some distance on the north side of that sea-loch the thrust plane is nearly flat or even inclines to the north-west, the mass of piled-up strata between the quartzite and the overlying gneiss increases in thickness towards the upper end of the inlet.

The gneiss immediately above the Glencoul thrust-plane has been sheared, and is crossed by bands of crushed gneiss parallel to the plane of movement. A little above that plane, however, the pre-Torridonian banding in the gneiss becomes quite distinct, and in many places can be seen to strike nearly at right angles to the thrust plane. The gneiss contains many basic dykes, now generally in the condition of hornblende-schist, though dykes of the same chemical composition and age in the unthrust region to the west are seldom foliated except near their edges, or along lines of special shearing.

In the south-east part of the line of section, and to the north-west of the Stack of Glencoul, most of the Cambrian rocks have been pushed forward on a thrust-plane which has a general north-westerly inclination (see Fig. 5). At their western margin, the basal quartzite (Ca), resting unconformably on the gneiss and traversed by several sills, is followed by the pipe-rock (Cb), and the serpulite-grit (Cd), without the intercalation of the fucoid-beds. Next in order comes the limestone, which is abruptly cut off by a minor thrust which brings up the quartzites. Here the pipe-rock is sheared and the pipes have been flattened and bent over in the direction of the line of movement—that is towards the W.N.W. It is noteworthy that these Cambrian rocks do not usually extend more than 100 or 200 yards from the line of section. They are flanked on the north and south sides either by the Lewisian Gneiss, or, close to the south-east end of the section, by the basal quartzite which lies unconformably on this gneiss. The thrust-plane has been sharply folded, and pieces of basal quartzite have been driven along it, and may be seen nipped into a steep cliff of gneiss.

The deformed pipe-rock is succeeded by sheared gneiss (μ), at the base of which lies a finely mylonised rock, about a foot thick, with laminæ hardly thicker than paper, composed probably of a mixture of gneiss and quartzite. Its laminæ are sometimes steeper than those of the quartzite below. Above the sheared gneiss come the puckered schists with thin siliceous streaks, termed by Mr. Clough the "Stack Schists," which are visible on the Stack of Glencoul. These rocks overlie the plane of the Moine thrust, and are inclined towards the E.S.E. at moderate angles.

Immediately to the south of Loch Glencoul the tectonic arrangement of the strata resembles that on the north side of the loch. The undisturbed Cambrian rocks from the basal quartzites to the fucoid-beds, dipping to the E.S.E. at 12°, are there overlain by the piled-up zones of the fucoid-beds, serpulite-grit, and basal dolomite, which, repeated by reversed faults, are truncated by the Glencoul thrust.

This line of displacement brings forward the southern continuation of the moved gneiss with its basic dykes north of Loch Beag, the thickness of the mass varying from 1500 to 1600 feet. The bare plane itself is well seen along the course of a footpath which traverses the slope on the south side of Loch Glencoul.

Tectonics of Quinag, Glas Bheinn, and Beinn Uidhe.—On the southern slope of Quinag (Spidean Còinich) the unconformability between the quartzites and the Torridon Sandstones (Bb) is exposed (Fig. 6), the former dipping towards the E.S.E. at angles varying from 4° to 8°, while the inclination of the latter is in the same general direction at from 15° to 20°. Both zones of the Cambrian quartzites (Ca, Cb) are followed in normal sequence by the fucoid-beds and serpulite-grit (Cc, Cd); but close to the high road leading to Kylesku the undisturbed strata are cut off by a major thrust-plane or "sole" (T), along which the fucoid-beds, serpulite-grit, and basal dolomite have been driven, being repeated by numerous reversed faults (t). This imbricate structure is merely a repetition of that already described on either side of Loch Glencoul. Eastwards the two lowest groups of the calcareous series (I. II.), repeated by reversed faults and thrown into gentle folds, occupy a low-lying plateau near Achumore, till they are over-ridden by the materials above the Glencoul thrust-plane. Owing to the covering of morainic drift the outcrop of this line of disruption east of Achumore is concealed, but its position is approximately at the base of the western slope of Glas Bheinn.

Above this thrust-plane and along the south-west declivity of the mountain, the various sub-zones of the pipe-rock (Cb), with the porphyrite sills (F), appear in inverted order, succeeded by the basal quartzites resting unconformably on the Lewisian Gneiss (A) with the basic dykes. The inversion of the Cambrian strata, so clearly displayed on this slope of Glas Bheinn, is an example of the usual folding over and buckling under in front of the displaced mass of gneiss. On the hilltop a part of the old archæan floor is laid bare, overlain, on the east side by both divisions of the quartzite with sills of igneous material (F).

Between Glas Bheinn and Beinn Uidhe a thrust, intermediate between the Glencoul and Ben More disruptions, intervenes, and repeats both the basal quartzites and the pipe-rock, which, on the lofty plateau of Beinn Uidhe, are arranged in a gentle synclinal fold. The model shows how the igneous sills (F) have been traced round this flexure. Here again, owing to the denudation of the quartzites, the Lewisian Gneiss comes to the surface (Fig. 6).

Descending the ridge towards Cailleach an Sniomh—a hill west of Gorm Loch Mòr—we cross the outcrop of the Ben More thrust-plane, which there gives rise to a well-marked hollow (Fig. 6). This disruption has brought westwards the Lewisian rocks with both divisions of the quartzites on to the basal quartzite. Three characteristic intrusive sheets appear in this area, one at the base of the false-bedded Cambrian quartzites, a second higher up in the same subdivision, and a third in the lowest sub-zone of the pipe-rock. Beyond Gorm Loch Mòr and near the Fionn Allt, the fucoid-beds, serpulite-grit, and basal dolomite are repeated mainly by folding. At the latter locality a lenticle of mylonised Torridon arkose (B)

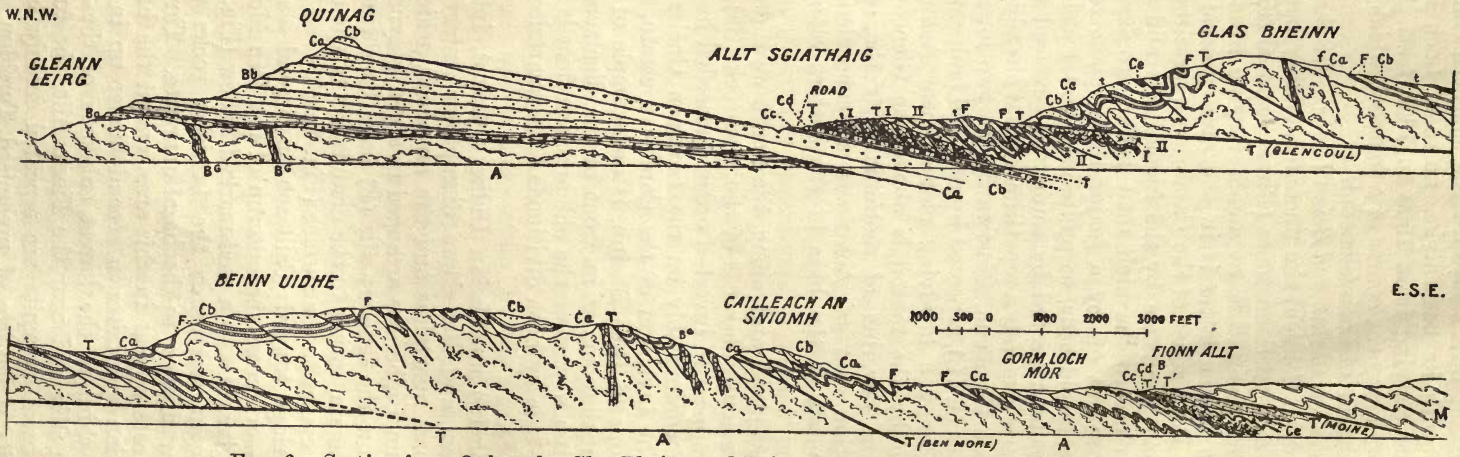

FIG. 6.—Section from Quinag by Glas Bheinn and Beinn Uidhe to Gorm Loch Mòr and Fionn Allt.

A. Lewisian Gneiss. BG. Dykes in Gneiss. Bb. Applecross group. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid, beds. Cd. Serpulite-grit. Ce. Dolomite and limestone (Cambrian). Ce I. Limestone (Ghrudaidh group). Ce II. Limestone (Eilean Dubh group). F. Intrusive Igneous Rocks. M. Eastern Schists. T. Thrusts. T′. Moine thrust. t. Minor thrusts. f. Faults.

underlies the Moine thrust-plane (T′) above which the great series of Eastern Schists supervenes.

Tectonics of Beinn Gharbh, Cnoc an Droighinn, Beinn an Fhurain and Ben More.—The intrusive sheets of albite-porphyrite that pierce the Torridon Sandstone on Beinn Gharbh are clearly shown in the model and in the accompanying section (Fig. 7). The gently undulating plateau of Lewisian Gneiss upon which the Torridonian strata rest is illustrated. On the eastern slope of the hill the basal quartzites lie partly on the Torridon Sandstone and partly on the Lewisian Gneiss—one of the typical examples of the double unconformability of the quartzites in the undisturbed area to the west of the post-Cambrian displacements. Next in order follow various sub-zones of the pipe-rock, which, together with the underlying false-bedded grits, are traversed by porphyrite sills.

From the eastern side of the alluvium at the head of Loch Assynt rise the piled-up fucoid-beds, serpulite-grit, and basal dolomite charged with *Salterella*. Two basic sills are here interposed, one between the serpulite-grit and the bottom of the calcareous series, and the other in the Ghrudaidh group (I). These are followed by the Eilean Dubh dolomites and limestones (II), resting on different members of the lowest division of the calcareous series and repeated by reversed faults. That the dolomites and limestones in this portion of the plateau are not arranged in an inverted synclinal fold can be demonstrated in a conclusive manner, for within a distance of half a mile from Loch Assynt the piled-up limestones are truncated by another major thrust, which has brought up the fucoid-beds, serpulite-grit, and basal dolomites, and has pushed them over the Eilean Dubh beds.

About half a mile north-east from Inchnadamff Hotel the position of the Glencoul thrust-plane is defined by a well-marked feature, which skirts the escarpment of quartzites on the west slope of Cnoc an Droighinn. These strata have been driven on to the dolomites of the Ghrudaidh group. Though complicated by the recurrence of minor thrusts and the presence of numerous sills of igneous material, both divisions of the quartzite on that hill may be described generally as forming an inverted anticline and syncline on a core of gneiss. Two intrusive sheets of porphyrite (F) here occur near the top of the lower division of the quartzites (Ca), and one of ægirine-felsite near the base of the lowest sub-zone of the pipe-rock.

East of Cnoc an Droighinn a thrust occurs, which brings forward a mass of Lewisian Gneiss (A) with basic dykes exposed on the north-west slope of Beinn an Fhurain. The basal quartzites (Ca) resting unconformably on the Lewisian floor can be traced round this inlier, though frequently in an inverted position. Eastwards the crest of the mountain is mainly composed of pipe-rock (Cb), overlain by fucoid-beds (Cc), and serpulite-grit (Cd), repeated by minor thrusts, and accompanied by intrusive sheets which resemble the types on Cnoc an Droighinn, and occupy similar horizons.

The position of the outcrop of the Ben More thrust lies on the east side of the peaty hollow between Beinn an Fhurain and Na Tuadhan, but it is there concealed by rock débris. Above this plane occur the stupendous folds of Cambrian strata on Na Tuadhan, in advance of the great displaced mass of Lewisian Gneiss on Ben More. This mountain (2824 feet), with a cliff about 1100 feet high on its

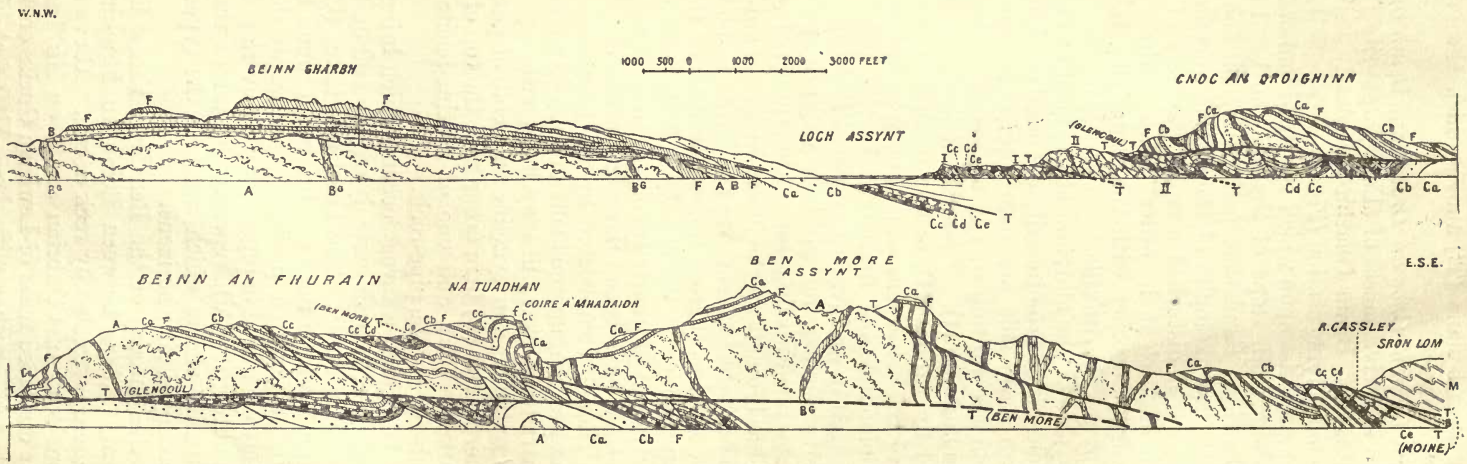

FIG. 7.—Section from Beinn Gharbh by Cnoc an Droighinn, Beinn an Fhurain, and Ben More to the River Cassley.

A. Lewisian Gneiss. Bg. Dykes in Gneiss. B. Torridon Sandstone. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce. Limestone. Ce I. Limestone (Ghrudaidh group). Ce II. Limestone (Eilean Dubh group). F. Intrusive Igneous Rocks. M. Eastern Schists. T. Thrusts. T'. Moine thrust. f. Faults.

eastern face, partly bounds the great corrie on the north-west side of Ben More (Coire a' Mhadaidh). Both divisions of the Cambrian quartzites (Ca, Cb), are here arranged in a great inverted arch and trough, which are readily recognised from the surrounding peaks. The unconformable boundary line between the basal quartzites and

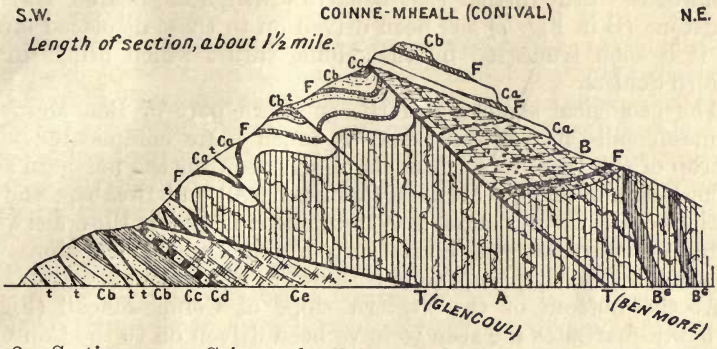

FIG. 8.—Section across Coinne-mheall from one of the sources of the Traligill east to Corrie a' Mhadaidh.

A. Lewisian Gneiss. Bg. Dykes in Gneiss. B. Torridon Sandstone. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce. Limestone. F. Intrusive Igneous Rocks. T. Thrusts. t. Minor thrusts.

the Lewisian Gneiss can be followed round the base of the great crag on the east side of the mountain, and northwards for more than a mile to Corrie a' Mhadaidh Beag, with a porphyrite sill along the junction (see Fig. 7 and the model).

On the north-west slope of Ben More, facing Corrie a' Mhadaidh,

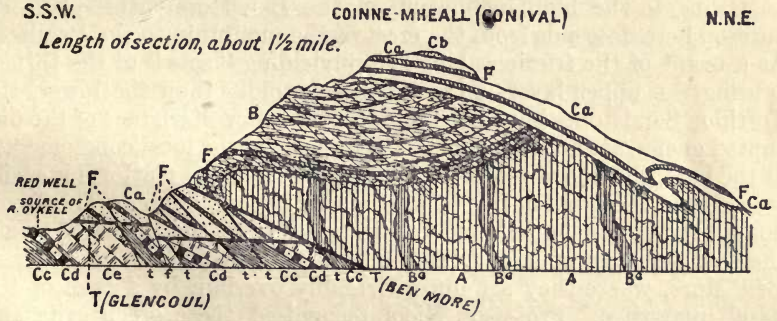

FIG. 9.—Section from the Beallach across Coinne-mheall to Corrie a'Mhadaidh.

A. Lewisian Gneiss. Bg. Dykes in Gneiss. B. Torridon Sandstone. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce. Limestone. F. Intrusive Igneous Rocks. T. Thrusts. t. Minor thrusts. f. Faults.

the Lewisian rocks are covered unconformably by the basal quartzite (Ca) with the intrusive sheets (F). Though the quartzites here are not deformed, the porphyrite sill at their base is highly sheared.

On the eastern slope of Ben More, towards the head waters of the River Cassley, near Sròn Lom, the Lewisian Gneiss with its basic dykes is overlain unconformably by the basal quartzite (Ca), followed by all the sub-zones of the pipe-rock (Cb), the fucoid-beds (Cc), the

serpulite-grit (Cd), and the basal dolomites of the Ghrudaidh group (Ce) traversed by a few reversed faults. Here the various sills in the quartzites occupy their proper respective horizons. Eastwards, the deformation resulting from the post-Cambrian movements becomes more pronounced in the intrusive sheets, the quartzites and the fucoid-beds. Still further east a narrow wedge of sheared Torridon Sandstone (B in Fig. 7) has been driven on to these displaced strata, but it is soon truncated by the Moine thrust which brings in the Eastern Schists.

The geological structure of the southern part of Ben More and Coinne-mheall—its western peak—is much more complicated. The outcrop of the Ben More thrust is clearly seen on the northern slope of the Beallach or pass between Coinne-mheall and Breabag, and the relations of the thrust masses may be studied in detail in the crags which stretch eastwards to the corrie surrounding Dubh Loch Mòr. The structure of this complex ground is shown in Figs. 8 and 9.

At the bottom of the western slope of Coinne-mheall (Fig. 8) the basal quartzites are seen to have been driven on to the Cambrian dolomites by the Glencoul thrust. As the burn section on this declivity is followed up to the 2500 ft. contour line, the strata exposed are found to consist almost wholly of these quartzites (Ca) with their sills (F). They are repeated by inverted folds and minor thrusts (t) in such a way as to indicate that they must form only a comparatively thin veneer over the concealed Lewisian rocks. About the 2500 ft. level the basal quartzites are followed by the various sub-zones of the pipe-rock (Cb), with their sills (F) and the fucoid-beds (Cc). Here the sequence is interrupted by the Ben More thrust, which brings forward the basal quartzites, resting unconformably on the Torridon Sandstone (B) and the Lewisian Gneiss (A).

Owing to the high inclination of the Ben More thrust-plane its outcrop here descends from the crest of the mountain to the Beallach. As a result of the friction along the unyielding " sole " of the thrust, causing the upper layers to move more rapidly than the lower, the Torridon Sandstones have been folded over the western face of the disrupted gneiss, as shown in Fig. 9. By means of the local conglomerate at the base, the line of junction with the old Lewisian platform is easily traced, and the proof of inversion is placed beyond doubt. The Torridonian strata can be followed continuously from the Beallach, round the south-eastern spur of Coinne-mheall to the southern shoulder of Ben More, where they are unconformably overlain by a cake of the basal quartzites. Professor Nicol recognised these green grits and sandstones as the true western red sandstone (Torridon) brought up in the centre of the so-called " upper quartz-rock." He further held that granitic gneiss and mica-slate with intrusive igneous rocks form the nucleus of the mountain, throwing off the quartzite all around, as from a great centre of elevation.*

In the Beallach of Coinne-mheall the dip of the Ben More thrust-plane becomes almost flat, and hence its outcrop can be followed for two miles and a half down the River Oykell. Along the line of outcrop the Torridon Sandstones with their basal conglomerate (" the button stone ") reappear on the east side of the valley, dipping underneath the Lewisian Gneiss in inverted order. There can be no doubt,

* *Quart. Journ. Geol. Soc.*, vol. xvii. 1861, pp. 96–99.

however, that this strip of Torridonian strata is merely a continuation of the mass on Coinne-mheall and Ben More, as shown in Fig. 10, the intervening portion having been removed by denudation.

Dr. Callaway noted the superposition of the Torridon grits upon the gneiss on Coinne-mheall and Ben More, and the inversion of these sediments beneath the same mass of gneiss on the east side of the Oykell valley * (Fig. 10).

Tectonics of Canisp, Beinn an Fhuarain, Breabag, and Sgonnan Mòr. —On the slopes of Canisp the double unconformability of the quartzites (Ca, Cb) on the Torridon Sandstone (Bb) and on the Lewisian rocks (A) is exposed. East of the River Loanan indications may be observed of the piling-up of the fucoid-beds, serpulite-grit, and basal dolomite by reversed faults, which are truncated by a major thrust that has brought westwards the two lowest groups of dolomite and limestone (Fig. 11).

A glance at the section will show the relations of the outlier of thrust materials above the Ben More thrust-plane on Beinn an Fhuarain to the piled-up Cambrian strata beneath. In the core of the outlier there is a small development of Lewisian Gneiss (A), overlain

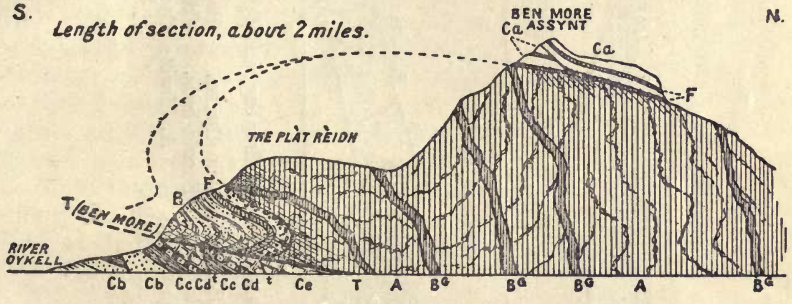

FIG. 10.—Section from the Oykell Valley across the Plàt Rèidh and Ben More.

A. Lewisian Gneiss. Bg. Dykes in Gneiss. B. Torridon Sandstone.
Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds.
Cd. Serpulite grit. Ce. Limestone. F. Intrusive Igneous Rocks.
T. Ben More thrust. t. Minor thrusts.

unconformably by Torridon grits and sandstones (Bb). On the north-west face of the hill the basal quartzites (Ca) appear in inverted order immediately above the thrust-plane, and pass transgressively across the gneiss and the Torridonian strata. The Allt nan Uamh (Burn of the Caves), by carving a deep channel through the underlying calcareous rocks, has isolated the outlier on Beinn an Fhuarain from the smaller mass on Beinn nan Cnaimhseag on the north side of the stream. Along the north margin of the latter outlier the bare thrust-plane of Eilean Dubh dolomite is well displayed. It is inclined to the west at 15°.

The broad dome on Breabag consists of a compound anticline, composed of thrust zones of basal quartzites (Ca), pipe-rock (Cb), and fucoid-beds (Cc). At one place, the serpulite-grit (Cd) is found on the high plateau. A striking feature of the mountain is the repetition by folds and reversed faults of two intrusive sheets (FF), one in zone III. of the pipe-rock and the other in zone V. of that division or in the fucoid-beds. In the pass or hollow between Breabag

* *Quart. Journ. Geol. Soc.*, vol. xxxix. 1883, p. 382.

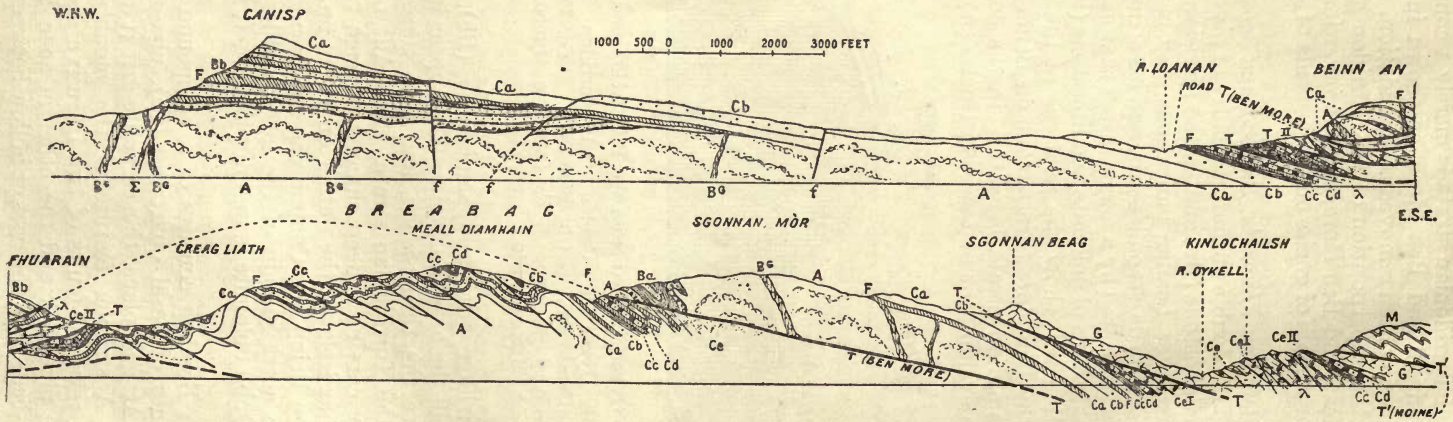

FIG. 11.—Section from Canisp by Beinn an Fhuarain, Breabag, and Sgonnan Mòr to Kinlochailsh.

A. Lewisian Gneiss. Bg. Basic Dykes in Gneiss. Σ. Ultra-basic Dykes in Gneiss. Ba. Diabaig group (Torridonian). Bb. Applecross group. Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce. Limestone. Ce I. Limestone (Ghrudaidh group). Ce II. Limestone (Eilean Dubh group). A. Marble (Cambrian). F. Porphyrite sills. G. Syenite. M. Eastern Schists. T. Thrusts. T′. Moine thrust. f. Faults.

and Sgonnan Mòr, the piled-up Cambrian zones are abruptly cut off by the Ben More thrust (Fig. 11).

The tectonic arrangement of the strata above this plane of disruption on Sgonnan Mòr is merely a counterpart of that on Ben More. Here a mass of Lewisian Gneiss (A) appears with its basic dykes, and with the Torridon Sandstone (Ba) inverted beneath it. The double unconformability of the quartzites is displayed, and some of the characteristic intrusive sheets are to be seen on their respective horizons.

Eastwards on Sgonnan Beag (see Fig. 11 and the model) there is a mass of syenite similar to that on Cnoc na Sròine. Along its western margin it is bounded by a thrust, and passes transgressively across the Lewisian rocks, both divisions of the quartzite, the fucoid-beds, and serpulite-grit. On its eastern side, near Kinlochailsh, it is intrusive in the Cambrian dolomites and limestones, which are there converted into marble (λ). East of the marble at Kinlochailsh a narrow band of sheared granitoid rock (G) appears below the Moine thrust-plane (T′), which evidently belongs to the same series of intrusions. Here, as elsewhere, this great displacement ushers in the Eastern Schists.

Tectonics of the Area south of Canisp and Breabag.—The tectonic arrangement of the strata in the belt of complication south of Canisp and Breabag is not so clearly displayed as that in the mountainous region to the north. A large part of the southern area is covered with peat and drift, and the precise position of the boundary lines is therefore to some extent conjectural.

The outcrop of the Ben More thrust-plane sweeps south-eastwards from Sgonnan Beag by Strathsheaskich to the north-west base of Cnoc a' Chaoruiun, thence westwards around Cnoc na Glas Choille and south by Cnoc nan Imirean, where it is overlapped by the Moine thrust. Outliers of the displaced materials above this plane occur far to the west between Loch Awe and Càm Loch, near Loch Urigill, at Am Pollan, Druim Pol Eòghainn, and other localities. The most westerly outlier, which covers the top and southern slopes of Ledbeg Hill, contains a core of Lewisian

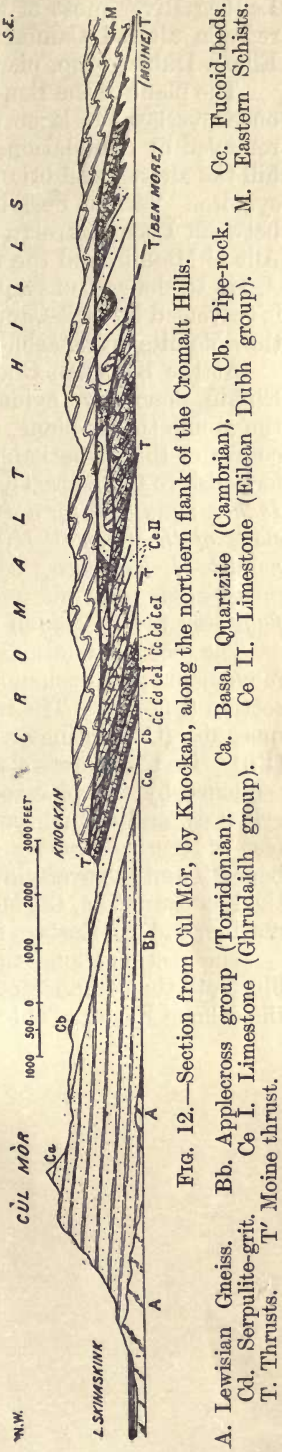

FIG. 12.—Section from Cùl Mòr, by Knockan, along the northern flank of the Cromalt Hills.

A. Lewisian Gneiss. Bb. Applecross group (Torridonian). Ca. Basal Quartzite (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit. Ce I. Limestone (Ghrudaidh group). Ce II. Limestone (Eilean Dubh group). M. Eastern Schists. T. Thrusts. T′ Moine thrust.

Gneiss, overlain by the basal quartzite and the pipe-rock. Near the Ledbeg River most of them are composed of basal quartzites which rest on altered Cambrian dolomites and limestone, chiefly of the Eilean Dubh group, pierced by granite intrusions.

The plane of the Ben More thrust and the materials above it, which once overlay the large plutonic mass of Cnoc na Sròine have been removed by denudation. At the base of the north-west slope of that hill the altered Cambrian dolomite appears not far from the nepheline-syenite. Various outlying patches of marble occur on the peaty flat between Loch Borrolan and Loch Urigill, and on the moor between Allt a' Mhuilin and the main outcrop of the Ben More thrust-plane. Again to the east of Elphin the tract of thrust dolomite and limestone is traversed by post-Cambrian igneous intrusions, which locally change the dolomite into marble.

At the Knockan Crag, about two miles south from the village of Elphin, conclusive evidence is afforded of the remarkable overlap of the Moine thrust-plane. From the base of the Stack of Glencoul the course of this remarkable disruption is generally southwards by Kinlochailsh to the River Oykell and Allt Ealag, where the trend is S.S.W. *It then runs west for a distance of six miles along the base of the north slope of the Cromalt Hills to the cliff about one mile S.S.W. of the hamlet of Knockan, passing transgressively across the Ben More thrust-plane, and all underlying displaced materials till the quartzose flagstones rest directly on the undisturbed Cambrian strata.*

The tectonic relations of the strata produced by the post-Cambrian movements at Knockan are illustrated in the accompanying horizontal section (Fig. 12). The top of Cùl Mòr is capped by an outlier of basal quartzite (Ca) resting on a great pile of Torridon grits and sandstones (Bb). On the eastern slope the basal quartzites are followed in normal sequence by the pipe-rock (Cb), the fucoid-beds (Cc), the serpulite-grit (Cd), and a small portion of the basal dolomite (Ce). Here a few feet of crushed marble are visible between the undisturbed strata beneath and the overlying Eastern Schists ; but, at the southern end of the Knockan Crag, the Moine thrust-plane has overlapped the crushed marble, and the Eastern Schists rest directly on the basal dolomite.

The section along the southern edge of the model and Fig. 12 illustrate the complicated relations of the strata concealed underneath the cake of Eastern Schists on the Cromalt Hills.

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